MISCELLANEOUS PAPER NO. 6-926

DESIGN, ANALYSIS, AND CONSTRUCTION OF PRECAST CONCRETE ELEMENTS WITH BAMBOO REINFORCEMENT

by

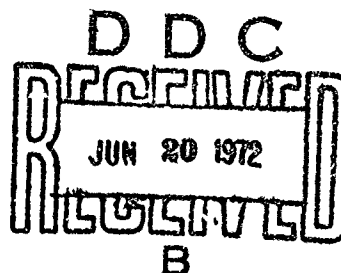K. L. Saucier

E. F. Smith

September 1967

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

20

MISCELLANEOUS PAPER NO. 6-926

DESIGN, ANALYSIS, AND CONSTRUCTION OF PRECAST CONCRETE ELEMENTS WITH BAMBOO REINFORCEMENT
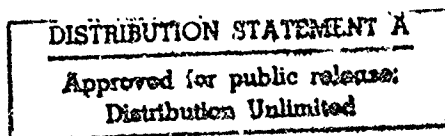
by

K. L. Saucier

E. F. Smith

September 1967

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

FOREWORD

The investigation on which this paper is based was conducted under Department of the Army Project 1-A-0-13001-A-039, "Director's In-House Laboratory Initiated Research Program," sponsored by the U. S. Army Materiel Command and reported in the Waterways Experiment Station Technical Report No. 6-646, May 1964.

This paper was prepared at the request of Brigadier General W. C. Hall, USA, Ret,, Editor, The Military Engineer, for publication in The Military Engineer. The paper has been reviewed and approved for publication by the Office, Chief of Engineers.

Preparation of the paper was accomplished at the Concrete Division, U. S. Army Engineer Waterways Experiment Station, under the direction of Mr. Bryant Mather, Chief, Concrete Division.

Director of the Waterways Experiment Station during the preparation of the paper was Colonel John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

DESIGN, ANALYSIS, AND CONSTRUCTION OF PRECAST CONCRETE
ELEMENTS WITH BAMBOO REINFORCEMENT

by

KENNETH L. SAUCIER* and EUGENE C. SMITH**

INTRODUCTION

The problems and advantages of the use of bamboo as a reinforcing
material have been studied in several countries[1,2,3]. The most exten-
sive investigation was undertaken at Clemson University in the United
States[3]. Advantages of the use of bamboo, where it is locally available
are its reasonably high tensile strength and its negligible cost.

The purpose of our research program was to study the feasibility
of using bamboo as the reinforcing material in precast concrete elements.
The objectives were to: (1) determine the load-carrying capabilities
and deflection limitations of precast concrete flexural elements with
bamboo reinforcement under both short-term and sustained loads; and
(2) modify current ultimate strength design and area-moment procedures,
as necessary, so that ultimate moments and deflections of bamboo-
reinforced concrete elements can be reasonably estimated.

It was assumed that the precast concrete elements would serve as
the basic element in light, temporary military concrete structures, and
that these structures would be constructed under field conditions. The
scope of the research program was limited to precast concrete elements

---

*   Research Civil Engineer, Concrete Division, USAEWES, Jackson, Miss.
**   Formerly Assistant to the Chief, Concrete Division, USAEWES,
     Jackson, Miss.

that: (1) have a reasonably long span length; (2) can be handled easily by two men; (3) use only bamboo as the reinforcement; (4) do not have excessive deflections under their own dead load or combined dead and live loads; and (5) have cross-sections that are relatively easy to form, fabricate, and precast.

CONSTRUCTION AND TESTING OF ELEMENTS

Materials

Concrete with an average slump of approximately two in. was used throughout this study. The average ultimate strength (f'_c) and the average chord Young's modulus of elasticity (E_c) between 250 and 1000 psi of the concrete in compression were determined to be 2750 psi and 3.51×10^6 psi, respectively, at an age of 28 days.

The bamboo culms, obtained locally (Clinton, Mississippi), had a diameter of approximately 1/2 in. at the large end, and a diameter of approximately 1/4 in. at the small end. Since field conditions were being simulated, the culms were cut the day before they were used in fabricating the beams. Thus, the curing of the culms was considered to be negligible.

Tests revealed the average ultimate tensile strength and modulus of elasticity of four specimens of bamboo to be 9480 psi and 1.86×10^6 psi, respectively. The stress-strain curves of the four bamboo specimens are shown in fig. 1. Uncured bamboo culms exhibit nonuniform character-istics which make precise analysis difficult.

Description of test elements

The design of the precast concrete flexural elements was dictated by the requirements imposed on the elements and the possible military uses to which the elements will be put; not by known loads and allowable stresses as is generally the case[5]. To meet the requirements, a beam was selected which had a cross-section 6-in. wide and 3-in. deep, but
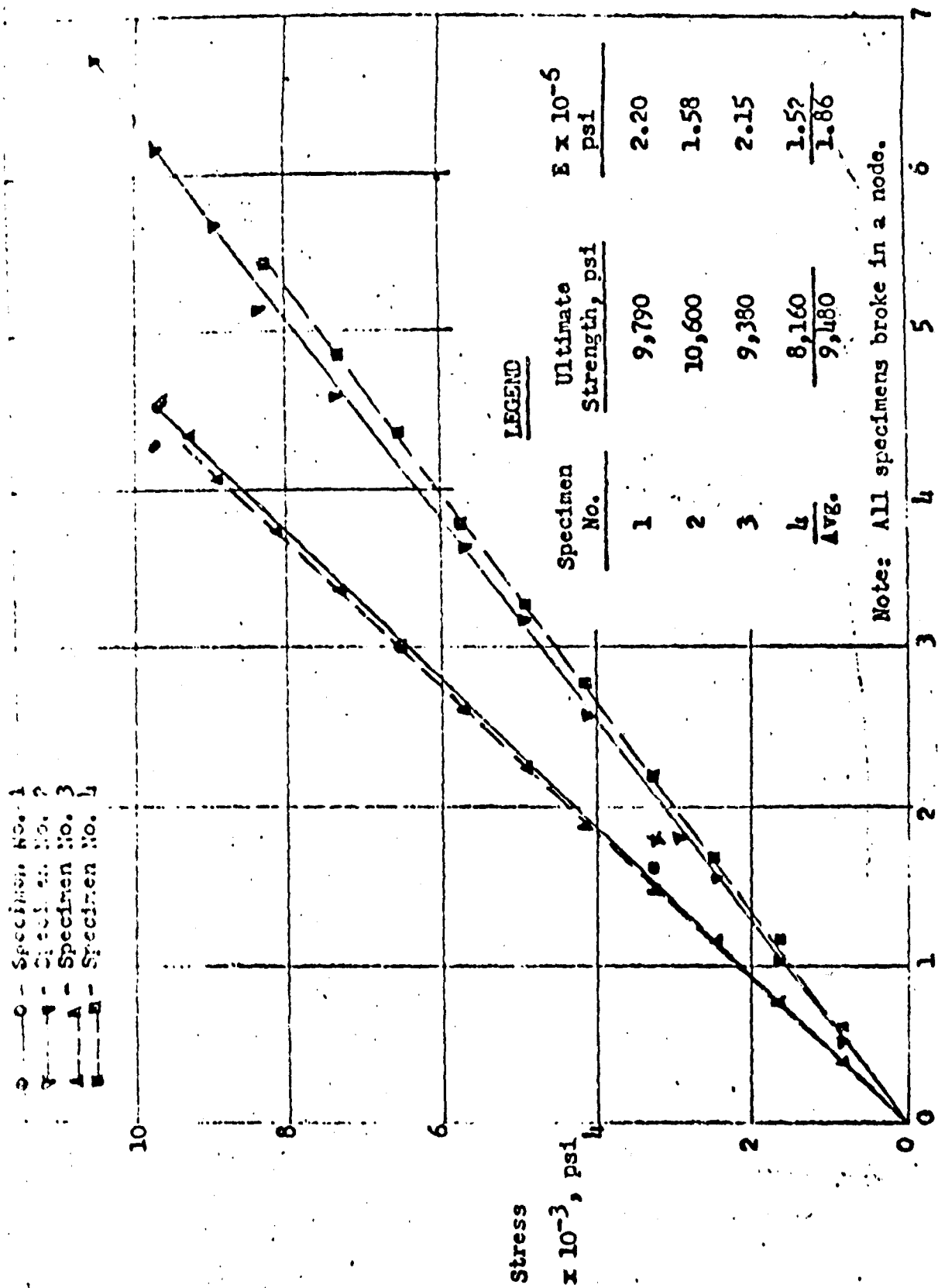
3

Fig. 1. Stress-Strain Curves for Bamboo Culms (Direct Tension Test)

with an inverted-V opening, thus making the beam, in effect, a beam channel. An over-all length of eight ft was arbitrarily selected, which resulted in a member weighing approximately 125 lb.

Two series of beams were made: series I designed to study the behavior of optimally reinforced precast concrete beams, and series II designed to study the behavior of maximally reinforced precast concrete beams. The longitudinal reinforcement for both series is shown in fig. 2.

To prevent flexural failure in the transverse direction, transverse reinforcement, consisting of 1/2-in. diameter by 5-in.-long culms, was spaced about 3 in. on centers and was placed so as to have a clear cover of about 1/4 in. at the top of the channel.
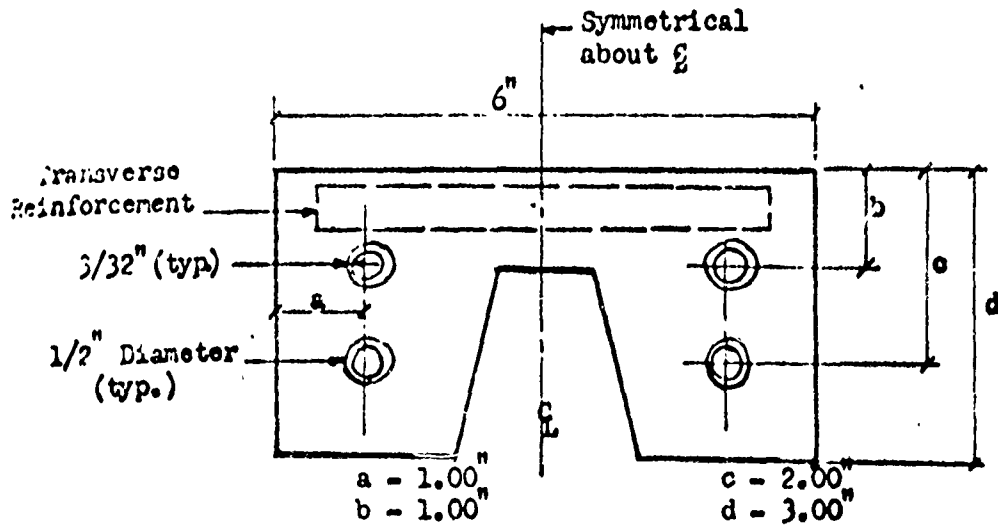
The beams were kept moist in their forms in the laboratory for a period of seven days, at which time the forms were stripped. The beams were then stored in fog at 73 degrees F and 100 percent relative humidity until the time of testing, at an age of 28 days.
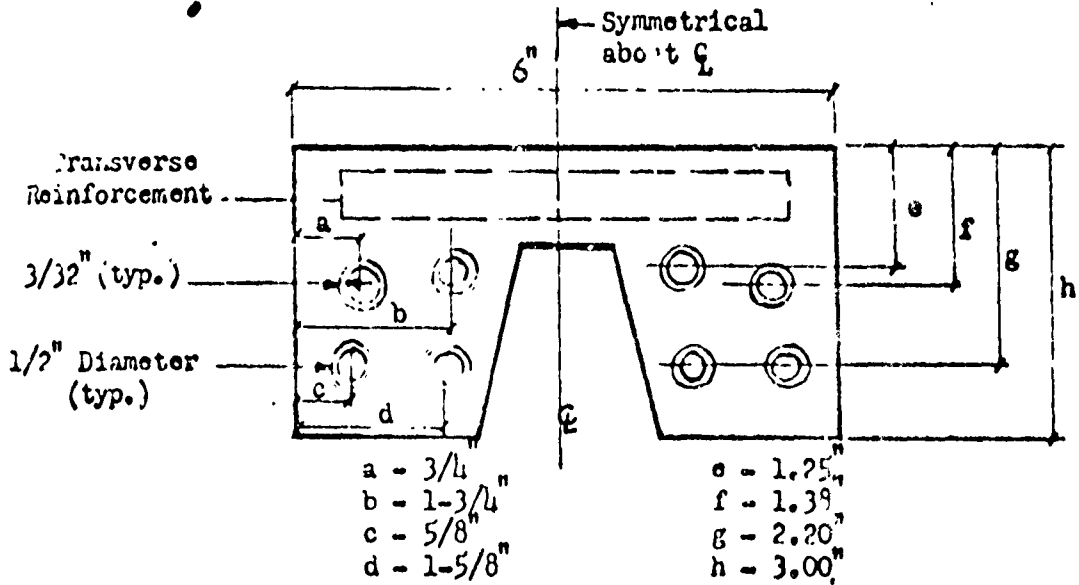
Outline of tests

The most severe manner in which the basic elements would be used would be as flexural members with a beam channel section, as shown in fig. 2. For this reason, only the basic element was tested in the feasibility study, and it was tested in the most severe manner, that is, with the smaller dimension as the depth.

Two types of loading were used in testing: third-point flexural load to failure (approximately 5 min. required) and 30-lb per ft uniformly distributed sustained loads (for approximately 42 days). For each type of loading, three series I beams were tested. Three beams were tested

Symmetrical about ℄

6"

Transverse Reinforcement

3/32" (typ)

1/2" Diameter (typ.)

b

c

d

℄

a - 1.00"
b - 1.00"

c - 2.00"
d - 3.00"

(a) Reinforcement for Series I Beams

Symmetrical about ℄

6"

Transverse Reinforcement

3/32" (typ.)

1/2" Diameter (typ.)

a

b

c

d

e

f

g

h

℄

a - 3/4"
b - 1-3/4"
c - 5/8"
d - 1-5/8"

e - 1.25"
f - 1.39"
g - 2.20"
h - 3.00"

(b) Reinforcement for Series II Beams

Fig. 2. Details of and Reinforcement for Series I and II Beams

9

in series II: two by third-point flexural load to failure and one by 30-lb per ft uniformly distributed sustained load.

Deflections at midspan of all beams were measured by dial gages.

RESULTS

Effect of amount of reinforcement

Average load-deflection curves for series I and II beams tested by third-point flexural loading to failure are presented in fig. 3. The series II beams sustained approximately twice the load that was sustained by the series I beams, at corresponding deflections. In addition, before failure of the beams occurred, the series II beams sustained loads to deflections approximately three times those of the series I beams. Therefore, if the maximum amount of bamboo reinforcement that can be reasonably placed in beams was used, the load-carrying capacity of bamboo-reinforced concrete flexural members would thus be maximized.

Average deflection-time curves for series I and II beams tested by 30-lb per ft sustained load are shown in fig. 4. It can be observed that the series II beams deflected more than the series I beams at all times. This is believed to be due to: (1) the creep characteristics of the uncured bamboo reinforcement, (2) the low modulus of elasticity of the bamboo (1.86×10^6 psi versus 3.51×10^6 psi for the concrete), and (3) the replacement of more concrete in the series II beams than in the series I beams by the lower-modulus bamboo reinforcement. If the entire concrete section is used as though it were uncracked throughout, and the bamboo is not counted except as offsetting the cracking effect, as is commonly assumed in practice[6], then it is obvious why the series II beams deflect more than the series I beams (see (3) above). The average deflections after 1000 hours of sustained load, approximately
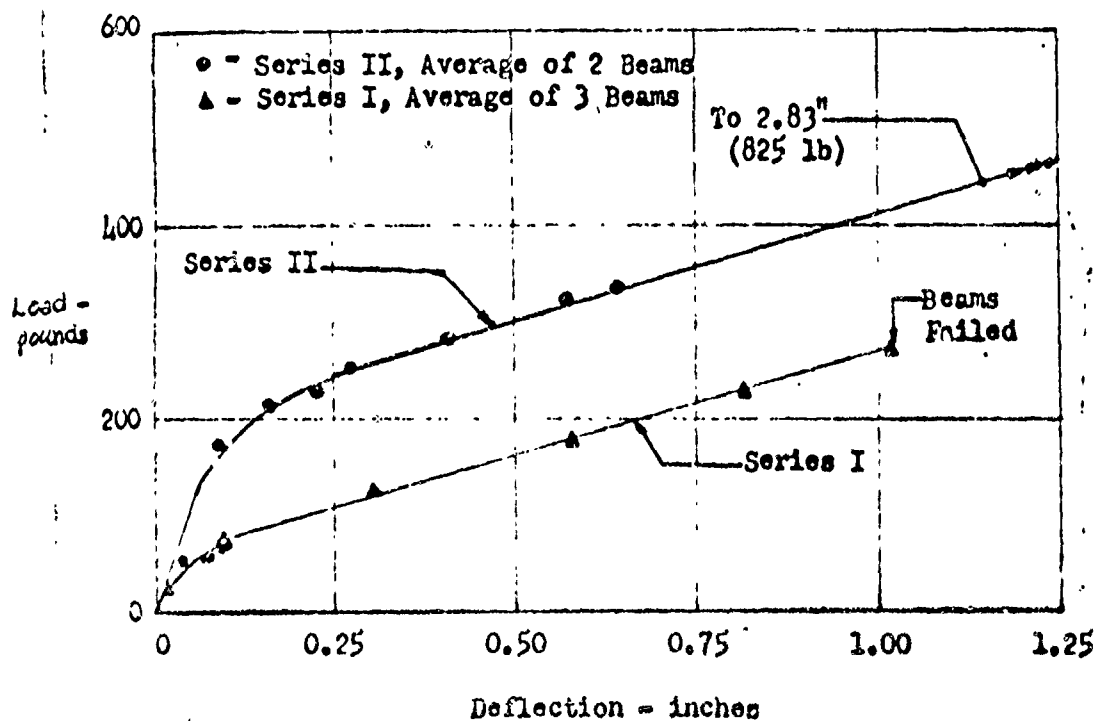
8

Fig. 3. Average Load-Deflection Curves for Series I and II
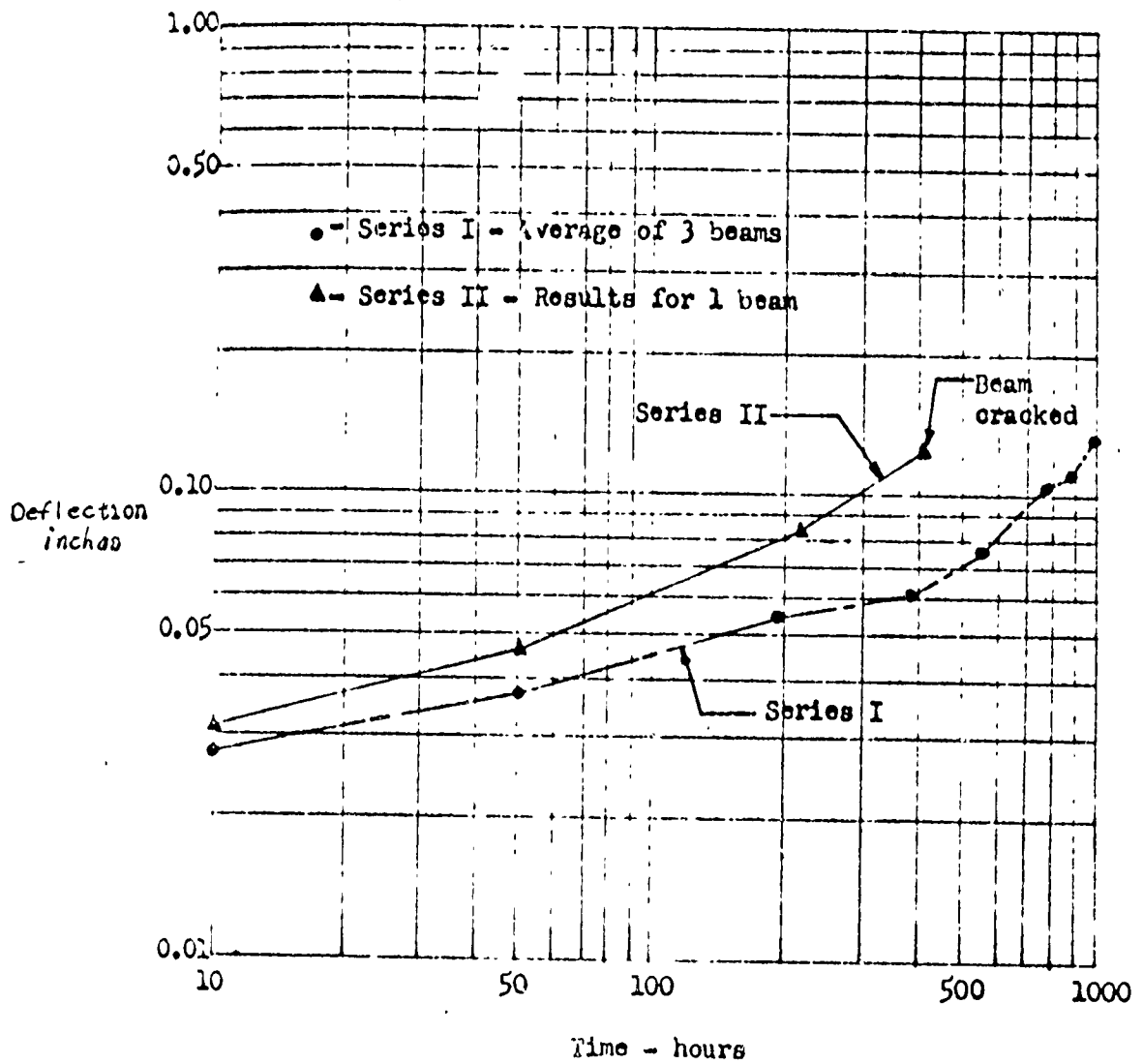Beams Third-Point Loading to Failure.

Fig. 4. Average Deflection-Time Curves for Series I and II Beams Showing the Effect of Amount of Reinforcement 30-lb per ft Distributed Load.

0.20 and 0.15 inches for the series II and I beams, respectively, probably would not be considered as excessive under temporary conditions since the series I and II beams sustained loads during short-term tests until deflections of approximately 1.0 and 3.0 inches, respectively, had been measured.

Effect of depth of beams

Fig 6 shows that the rate at which the deflections increase with time is also increasing. This is an indication that the depth of bamboo-reinforced concrete flexural members probably should be greater than 3 inches, which was used in this feasibility study. For a given span length and sustained load, the deflections are inversely proportional to the cube of the depth of a beam. If the depth of the bamboo-reinforced concrete beams was increased to 4 inches, the total weight of a beam would only be 173 lb, but the measured beam deflections would be decreased by a factor of 2.4. The deflections would then be equivalent to approximately (L/1100). This probably would be an adequate factor of safety against excessive long-time deflections.

An examination of sawed-off sections of the beams after test revealed that the bamboo reinforcement had "floated" up in the concrete during fabrication of the series I beams, but was rather evenly distributed throughout the series II beams. As a result, and also because four additional bamboo culms were used, when the concrete cracked initially, the transfer of load from the concrete to the reinforcement was not as pronounced in the series II beams as it was in series I beams.

Comparison of experimental and theoretical ultimate moments

For purposes of comparison, experimental and theoretical ultimate moments were calculated by using the laws of statics and the failure loads for three series I beams and two series II beams tested by third-point loading to failure. An ultimate strength design procedure was used to calculate the theoretical ultimate moments utilizing the usual assumptions[7,8].

The experimental and theoretical ultimate moments and the percent variation from the experimental ultimate moment are given in table I for each of the five beams. For the series I beams, it is apparent that the theoretical ultimate moments are in reasonably close agreement with the experimental ultimate moments; however, the theoretical ultimate moments in series II beams underestimated the experimental ultimate moments by approximately 20 percent. In other words, it appears that the more bamboo reinforcement that is placed in a beam with given cross-sectional dimensions, the less accurate any estimate of the ultimate moment will be.

Comparison of experimental and theoretical deflections

An attempt was made to compare the experimental and theoretical short-term and sustained deflections of the series I and II beams. Standard formulas for maximum deflections at midspan of simply supported beams with uniformly distributed and third-point loads were used to calculate the theoretical deflections. The moment of inertia calculated by assuming the uncracked transformed section gave values for theoretical deflections due to sustained loads within 100 percent of the average

12

TABLE I

COMPARISON OF EXPERIMENTAL AND THEORETICAL ULTIMATE MOMENTS

Beam Series	Load at Failure, P*	Uniformly Distributed Weight of Beam, w	Experimental Ultimate Moment, M_{us}**	Theoretical Ultimate Moment, M_u	Variation from Experimental Ultimate Moment
	(lb)	(lb/ft)	(in-lb)	(in-lb)	(percent)
I	228	14.8	4,668	5,132	+ 9.9
I	228	14.8	4,668	5,132	+ 9.9
I	278	14.8	5,418	5,132	- 5.3
II	825	14.0	13,560	11,158.9	-17.7
II	902	14.0	14,712	11,158.9	-24.2

* All beams were tested by third-point flexural loading.

** Experimental ultimate moments were calculated from the equation:.

$$M_{us} = (PL/6 + wL^2/8),$$

where P is the load at failure, L is the span length (7.5 ft), and w is the uniformly distributed weight of the beam (excluding the concrete displaced by the bamboo reinforcement.)

measured deflections at 1000 hours. Although such differences are not normally considered to be good agreement, it is believed that they are reasonable for precast concrete elements with bamboo reinforcement, since bond slippage between the concrete and the bamboo occurs, and there is considerable creep of the uncured bamboo.

Application

Such precast concrete elements could possibly be used for military purposes in a variety of ways. Two are described below.

a. The basic precast concrete elements could be used in a back-to-back fashion to form 6-in. wide by 6-in. deep I-beams to carry heavy loads over an 8-ft span. This could be accomplished by providing holes in the center of the elements during fabrication, and by tying the elements together. The I-beams could serve as supporting members for other elements which would be used to form a roof. For this use, the transverse reinforcement in the basic element would then act essentially as stirrups to resist vertical shear forces. To support the I-beams and roof-slab elements, a rectangular bamboo-reinforced concrete column could easily be formed and fabricated. The column could also serve as a beam-column to support precast elements which would be used to form a wall. Windows could easily be formed in the wall by fabricating only one-half of the basic element and using the half-element. Joint-connection problems would require some attention but could be adequately solved. Thus, it is believed that complete one-story, light, temporary concrete military structures could be constructed under field conditions using combinations of the basic element.

b. The basic precast concrete elements could serve also as short-span foot- or light-vehicle bridges. This would assist movement of troops and vehicles across deep trenches, creeks, and ravines. For relatively heavy loads (light vehicles), the basic element could be tied together back-to-back to form I-beams. The I-beams could be closely spaced together, and additional elements could be used to form bridge deck. For foot traffic, the elements could probably be used as planks without additional support.

CONCLUSIONS

The following general conclusions were reached:

a. Bamboo can be used as the reinforcing material in light, semi-permanent concrete military structures.

b. Ultimate strength design procedures, modified to take into account the characteristics of the bamboo reinforcement, can be used to estimate the ultimate load-carrying capacity of precast concrete elements with bamboo reinforcement.

c. As the percentage of bamboo reinforcement used in fabricating the beams increases, the estimate of the ultimate load-carrying capacity of the beams becomes less accurate.

d. Short- and long-term deflections of bamboo-reinforced concrete beams can only be approximately estimated by using the moments of inertia of either the cracked or the uncracked transformed section of the beams.

e. To maximize the load-carrying capability of a bamboo-reinforced concrete beam, as much bamboo as can be reasonably placed in the beam should be used.

f. To minimize long-term deflections, a minimum depth of 4 inches is recommended for flexural members.

g. No unusual difficulties should arise in fabricating and curing precast concrete elements with bamboo reinforcement under field conditions.

REFERENCES

1. Holme, A. S., "Substitutes for Steel in Reinforced Concrete Construction." Royal Engineers Journal, vol 54 (June 1940), pp 237-244. (Translated from an Italian publication.)

2. Mehra, S. R., Uppal, H. L., and Chedda, L. R., "Some Preliminary Investigations in the Use of Bamboo for Reinforcing Concrete." Indian Concrete Journal, vol 25, No. 1, pp 20-21.

3. Glenn, H. E., Bamboo Reinforcement in Portland Cement Concrete. Bulletin No. 4, Clemson Agricultural College, Clemson, S. C., May 1950.

4. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., Precast Concrete Elements with Bamboo Reinforcement, by Kenneth L. Saucier, May 1964, 22 pp (Technical Report No. 6-646).

5. Ferguson, Phil M., Reinforced Concrete Fundamentals, John Wiley & Sons, Inc., New York, 1958, pp 96-97.

6. Ferguson, Phil M., op cit., p 437.

7. Hognestad, Eivind, Ultimate Strength of Reinforced Concrete in American Design Practice, PCA Research and Development Laboratories Bulletin D12, pp 9-10.

8. Sinha, Nripendra C., and Ferguson, Phil M., "Ultimate Strength with High Strength Reinforcing Steel with an Indefinite Yield Point," Journal of the American Concrete Institute, April 1964, Proceedings, vol 61, No. 4, p 401.